Electromagnetic Field Effects in Semiconductor Crystal Growth

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Electromagnetic fields can interact with electrically conducting melts and substantially affect their fluid-flow processes. Indeed, the intriguing possibility exists of using these fields to control fluid flow in the melt during the solidification of semiconductor alloys. However, before such a possibility can be realized, it is essential to conduct a basic study of the fundamental interactions that electromagnetic fields can have on fluid-flow processes during semiconductor crystal growth. Recent work on this effort has focused on both constructing a model growth cell in which the basic flow processes can be experimentally observed and developing a theoretical framework that addresses the issues involved.

A new theoretical formulation of combined electromagnetohydrodynamics has been developed and shows the inconsistencies and shortcomings of the existing separate electrohydrodynamic and magnetohydrodynamic theories. The new model is for three-dimensional, unsteady, viscous fluid flows involving electrically charged particles and electric polarization and magnetization effects. All interaction between externally applied and internally induced electric and magnetic fields is incorporated into the model. An eigenvalue analysis of the governing system of nine nonlinear, coupled, differential equations has been performed. For certain combinations of material properties, it is possible to obtain complex conjugate eigenvalues, indicating that the hyperbolic-elliptic system could become inherently oscillatory. Future planned activities include numerical algorithm development and computer coding of the model.

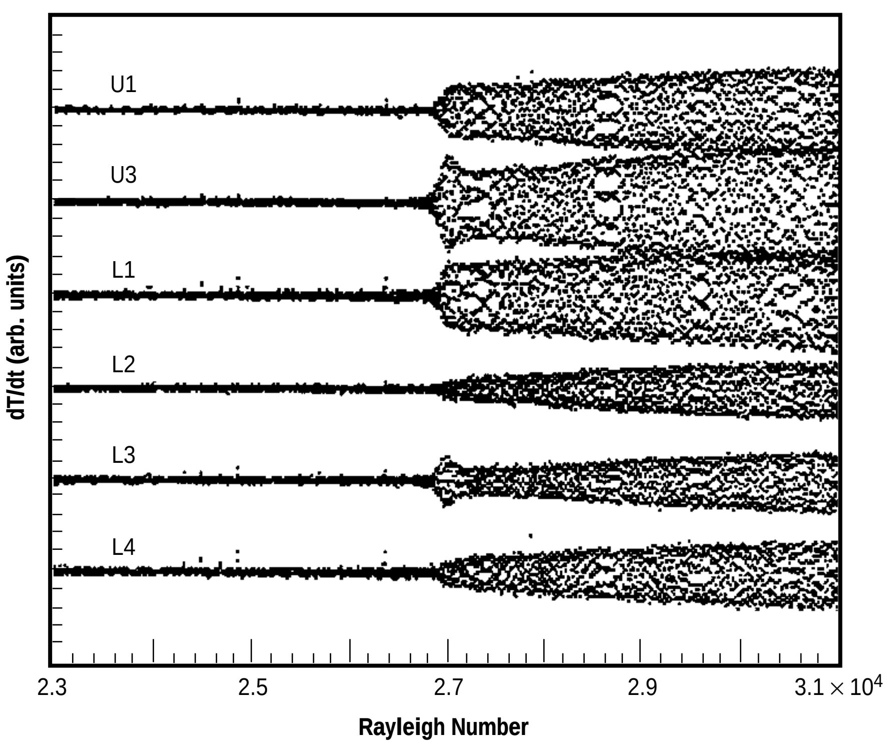

FIGURE 8.—Derivatives of thermistor signals versus Rayleigh number.

Experimentally, a cylindrical test cell was constructed and placed in the center of a rotating magnetic field. The cell contained liquid gallium. Thermistors were placed in the cell to record temperature changes, and researchers were to infer from them the nature of the fluid flow. The temperature difference between the top and bottom of the cell was slowly changed until transitions between fluid modes were observed. These transitions occurred at critical values of the Rayleigh number, a dimensionless number which is proportional to the temperature difference across the cell. A typical transition is shown in figure 8. The derivatives of the thermistor signals, designated "U1–L4," are plotted as a function of the Rayleigh number. The thermistor signals are vertically offset for clarity. When the Rayleigh number reaches 2.7×10^4, the flow transitions from being time-independent to time-dependent.

Critical Rayleigh numbers were measured as a function of rotating magnetic field strength, and several different fluid stability regimes were identified. For weak rotating magnetic fields and small Rayleigh numbers, a regime was identified as having laminar flow. In that regime, the rotational fluid velocity depended on the magnetic field strength squared. The importance of this observation is that it indicates that a flow regime exists in which the benefits of a rotating magnetic field on the crystallization process are not compromised by time-dependent flow.

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